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OPERANT-CONTINGENCY-BASED PREPARATION OF CHILDREN FOR FUNCTIONAL MAGNETIC RESONANCE IMAGING

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Functional magnetic resonance imaging (fMRI) is used to study brain function during behavioral tasks. The participation of pediatric subjects is problematic because reliable task performance and control of head movement are simultaneously required. Differential reinforcement decreased head motion and improved vigilance task performance in 4 children (2 with behavioral disorders) undergoing simulated fMRI scans. Results show that behavior analysis techniques can improve child cooperation during fMRI procedures.

DESCRIPTORS: differential reinforcement, performance accuracy, motion control, behavioral pediatrics, magnetic resonance imaging

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Magnetic resonance imaging (MRI) is a noninvasive procedure for studying the brain. Motion control is essential to the success of MRI and can be facilitated using either sedation or operant techniques. The benefits of sedation are lower cost and speed of effect. Operant techniques may be preferred when (a) research studies of brain structure are conducted using MRI with vulnerable populations such as children and sedation risks are unacceptable or (b) studies of brain function require motion control *and* participation in functional tasks (e.g., stimulus recognition, discrimination, or problem solving) using functional magnetic resonance imaging (fMRI). Operant techniques have facilitated MRI studies of brain structure in children and individuals with developmental disabilities (Slifer, Cataldo, Cataldo, Llorente, & Gerson, 1993). Some recent fMRI studies have begun to include cooperative volunteer children as subjects (e.g., Hartnick, Rudolph, Willging, & Holland, 2001; Thomas et al., 2001). The present study tested the effects of using operant procedures to train motion control and task performance as might be required for child compliance with fMRI procedures.

METHOD

Four children (7 to 10 years old) participated. Two girls, Ellie and Kim, had no medical, behavioral, or developmental diagnoses, and were performing at grade level in school (similar to children studied by Slifer et al., 1993). Two boys, Timmy and Brandon, had been diagnosed with attention deficit hyperactivity disorder (ADHD). Brandon also had fetal alcohol syndrome. Both boys attended a regular class at grade level but received special education services. The children had no sensory or neuromuscular disorders. A simulated fMRI scanner was used, consisting of a stretcher (Model 900KD, Midmark Corp., Versailles, OH), a plastic tube-slide (0.61 m diameter by 1.2 m long; Game Time, Inc., Fort Payne, AL), a cartoon scanner façade depicting a spaceship, a helmet-like "head coil" with vision

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possible via attached mirror (standard on fMRI scanners), and tape-recorded fMRI noises played at 68 dB to 90 dB. Head supports and safety straps typically used for fMRI scans were used. Head movement was measured continuously in millimeters using a custom-made apparatus connected to the child's forehead by nylon string and an adhesive patch (see Slifer et al., 1993). The apparatus employed two potentiometers (Model RVBC2-S 340, Technology Instruments Corp., Acton, MA) and a desktop computer with DAS-8 data-acquisition board (Keithly Metrabyte Corp., Taunton, MA) to convert movement to digital data. The average rate of head movement was calculated by dividing accumulated millimeters by scan duration (in minutes). Training effects were demonstrated using a multiple baseline design across participants.

A vigilance task was used to simulate one type of participation that might be required during fMRI. The child lay supine in the mock scanner and watched a videotape on a color monitor (60.1 cm) using the head coil mirror. The videotape displayed color illustrations of familiar objects in random sets (e.g., horse, pencil, and book), which alternated at random intervals with a blank white screen. The child watched for a blue square and pressed a thumb button when it appeared and an index finger button when it disappeared (buttons were 6.4 cm diameter, 735 "Jelly Bean" switches, Don Johnston Co., Volo, IL). Button presses were recorded using a Best Switch computer interface device (Boston Educational Systems and Technology, Inc., Forest Hill, MA). Percentage correct performance was calculated by dividing the number of correct trials by the total number of trials and multiplying by 100%. Each simulated scan lasted 7 min. During baseline, the participant was given a brief demonstration of how to lie down, hold very still, and perform the vigilance task using the dominant hand for button pressing. No feedback about head motion or performance accuracy was provided.

During differential positive reinforcement, each session began with a review of previous session results; then the child chose a prize to earn for improved performance. The baseline instructions and demonstration were repeated. After the mock scan, the child was given immediate verbal feedback about his or her performance and, if the criterion for reinforcement was met, received praise and the prize. Criterion for reinforcement was defined as any increase of 1% or more compared to the preceding session (vigilance task), a decrease of 0.1 mm/min or more (head motion), or both. Reinforcement was contingent on improvement in both motion control and performance simultaneously for Timmy and Brandon, whereas for Kim and Ellie, reinforcement was initially contingent on task performance only, but later was contingent on both task performance and motion control.

RESULTS AND DISCUSSION

The results displayed in Figure 1 show that performances increased and head movement decreased as a function of the reinforcement contingencies. When the reinforcement contingency was applied simultaneously to motion and performance, accuracy increased on the vigilance task from a mean of 55% (range, 30% to 80%) for Timmy and 43% (range, 10% to 60%) for Brandon to means of 93% (range, 85% to 100%) and 76% (range, 50% to 95%), respectively. Head motion decreased from a baseline mean of 31.3 mm/min (range, 8.6 to 45.7) to a mean of 0.98 mm/min (range, 0.16 to 1.8) for Timmy, and decreased for Brandon from a baseline mean of 8.7 mm/min (range, 4.2 to 17.8) to a mean of 5.7 mm/min (range, 0.4 to 16.8). Contingent reinforcement increased the percentage of correct responses on the vigilance task for

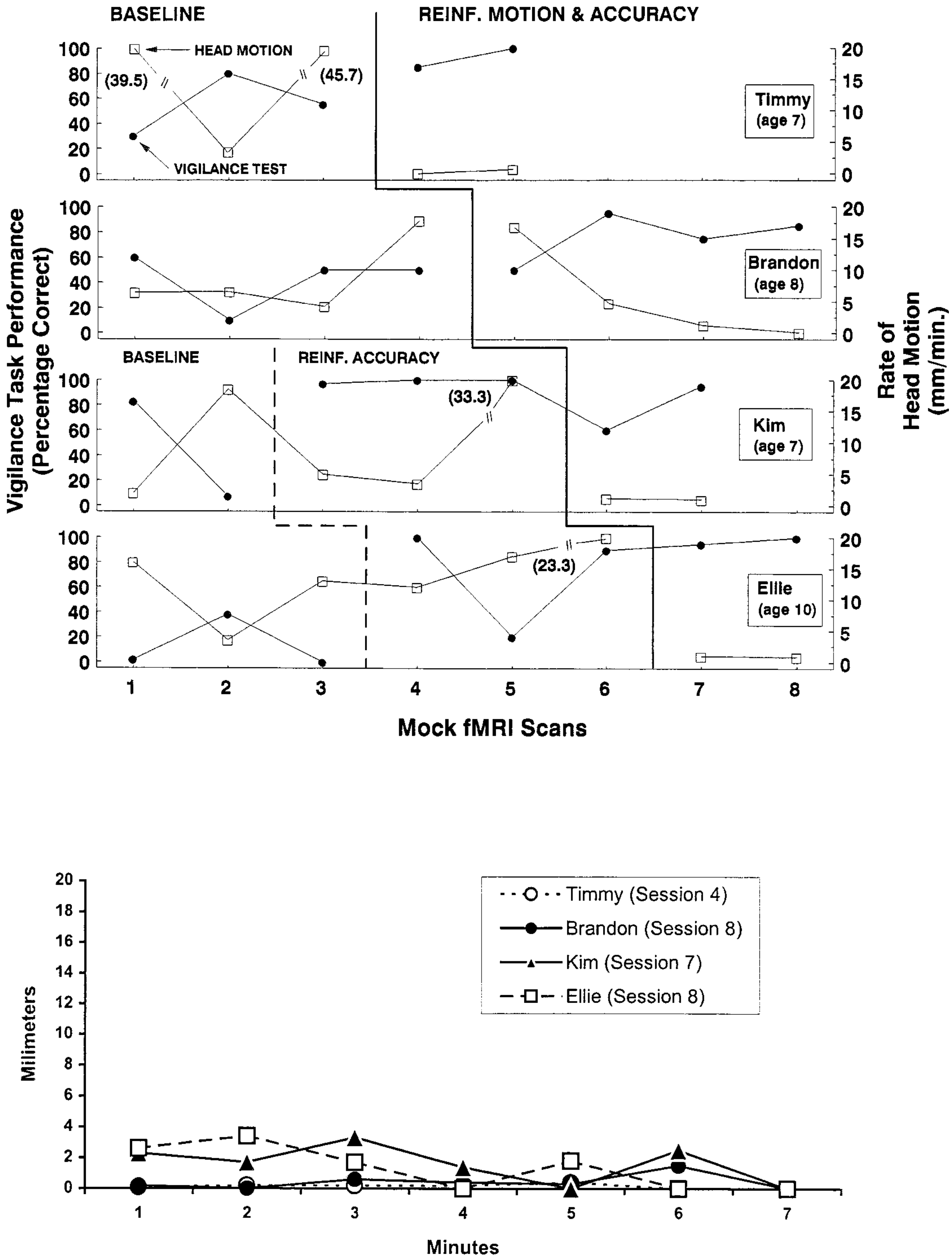

Figure 1. The top panel displays the percentage correct on the vigilance task (solid circles, vertical axis on the left) and rate of head motion in millimeters per minute (open squares, vertical axis on the right) across baseline and reinforcement conditions during simulated fMRI scans. The bottom panel displays the minute-by-minute head motion measured in millimeters during each child's best performance in the reinforcement condition.

Kim and Ellie from baseline means of 42% (range, 1% to 83%) and 13% (range, 0% to 38%) to treatment means of 90% (range, 60% to 100%) and 81% (range, 20% to 100%), respectively. When the same contingency was applied concurrently to motion control and performance accuracy, head motion decreased from a baseline mean of 12.5 mm/min (range, 2 to 33.3) for Kim and 16 mm/min (range, 3.5 to 23.3) for Ellie to means of 1.1 mm/min (range, 1 to 1.2) and 0.95 mm/min (range, 0.9 to 1), respectively, while gains in performance accuracy were maintained. Differential reinforcement successfully modified the children's task performance and head movement during simulated fMRI scans.

The minute-by-minute head motion for each participant's best mock scan in the treatment condition is also shown in the bottom part of Figure 1. Head movements were generally small (3.4 to 0.16 mm/min), but were not entirely suppressed. This study was conducted using an fMRI simulator and volunteers who were not scheduled for an actual fMRI scan. Some actual scanners are equipped with motion-correction capabilities.

Additional research is needed to determine if the procedures and magnitude of motion reduction described here will result in usable fMRI data among children with brain disorders and noncompliance. fMRI specialists evaluate head displacement in relation to three-dimensional units of volume called "voxels." Voxel size varies across scans as a function of the field of view and the number and width of sections into which it is divided. A typical voxel has a volume of 50 to 70 mm^3. A maximum head displacement in any one direction of >0.5 voxels or approximately 1.5 to 2 mm seems to be the limit for motion correction and the criterion for data rejection. The simulator in this study was not equipped to measure head motion in voxel units. More research is needed to determine the relation between motion measured in millimeters per minute during simulations and voxel units measured during actual fMRI scans. Also, additional research should investigate the validity and reliability of these training methods for children of varying ages and diagnoses performing more challenging tasks (e.g., degrees of discrimination or complex conditional discriminations) for 30 min or more in an active scanner.

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